INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NPTEL
NPTEL ONLINE CERTIFICATION COURSE

Refrigeration and Air-conditioning

Lecture-04
Aircraft Refrigeration Cycles-1

with
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Hello I welcome you all in the course on refrigeration and air conditioning today we will discuss the aircraft refrigeration cycles in this lecture we will be covering the requirement of cooling in airplane why use air cycle.

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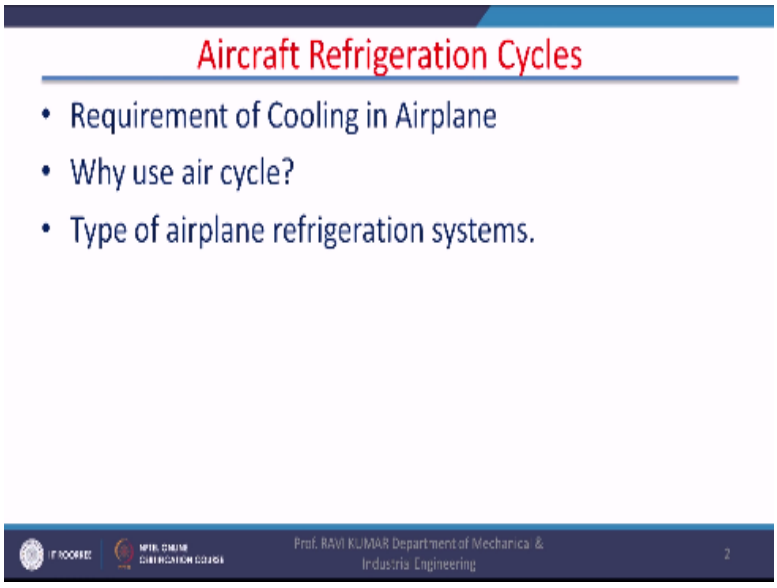

Type of airplane refrigeration system airplane is a special type of aircraft even a helicopter is an aircraft even a hot-air balloon is an aircraft but airplane is a special type of aircraft which has weighing a specific body it can be manual and it can be controlled and power so basically in this lecture we will be focusing on airplane refrigeration systems.

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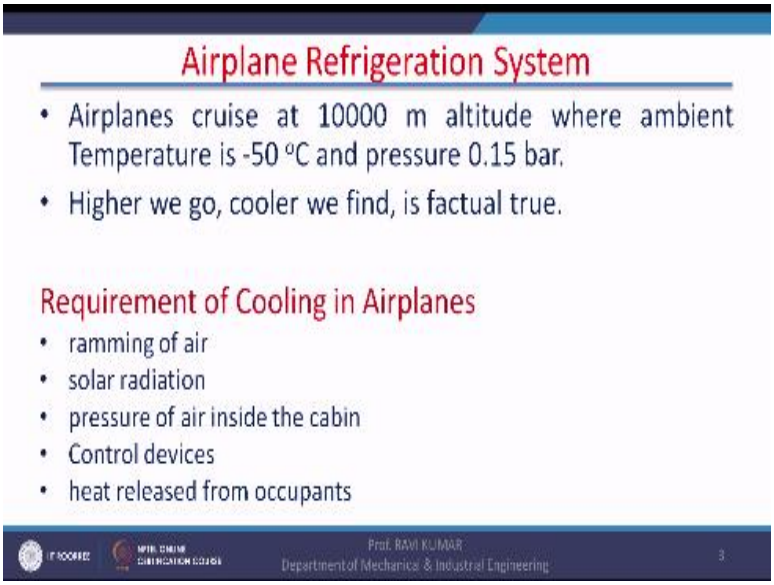

And first of all we will discuss the requirement of cooling in airplane now airplane moves at 1,000 meters around 10 kilometers above the Earth's surface where temperature is -50 degree centigrade and pressure is approximately 0.15 bar.

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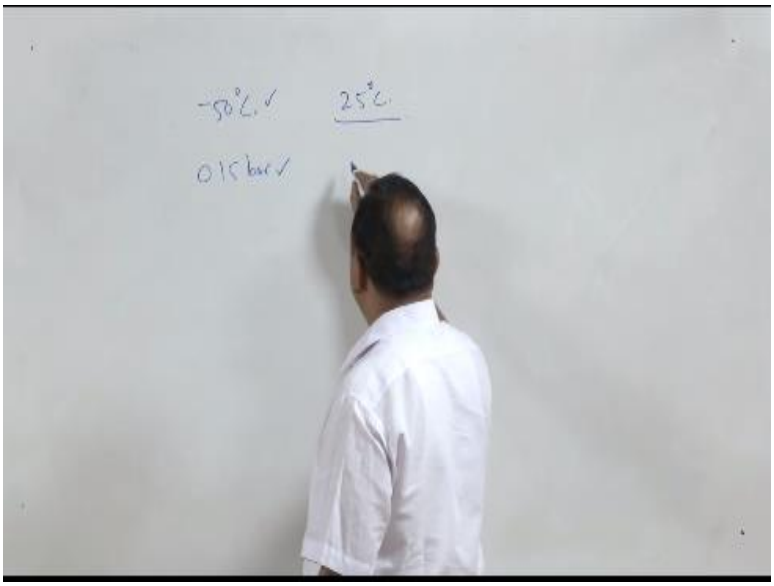

Neither we can survive under pressure of 0.15 bar nor we can survive under temperature of -50 degree centigrade because for our comfort the required temperature is 25 degree centigrade and pressure has to be in ideal condition 1 atmospheric pressure or 1 bar pressure or close to 1 bar pressure in any case 0.15 bar pressure no human being can survive so the pressure has to be increased in the airplane and temperature has to be increased.

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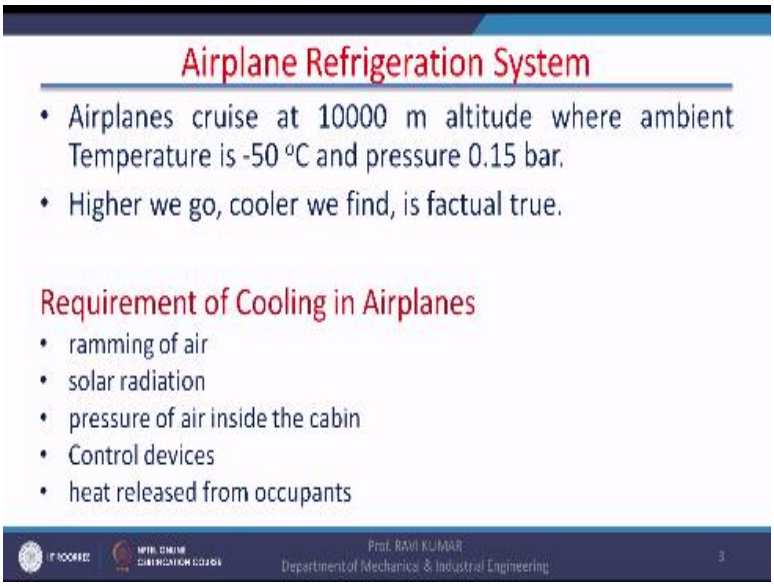

Higher we go from the Earth's surface we find that the temperature goes down right because the closest layer of air.

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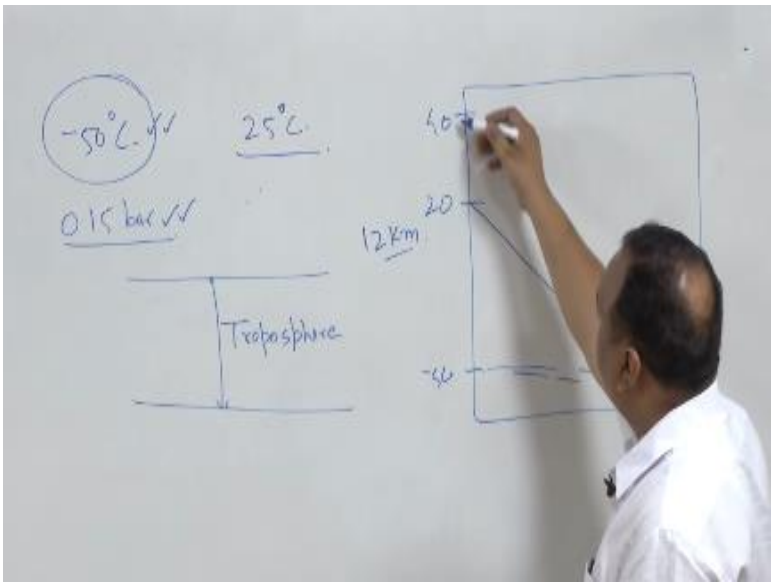

Over the Earth's surface is troposphere pressures up to 12 kilometers above the Earth's surface so most of the aircraft's they move in troposphere and temperature is most of the cases it is close to -50 degree centigrade irrespective of the fact the temperature or the earth surface if you draw it a chart for the variation of temperature with altitude suppose altitude is here is 12 kilometers or 10 kilometers and temperature is 20 this is 40 and this is -50 so at 10 kilometers attitude the temperature remain same this temperature does not vary with the temperature on the earth, now in the airplane for the air conditioning of airplane now we call.

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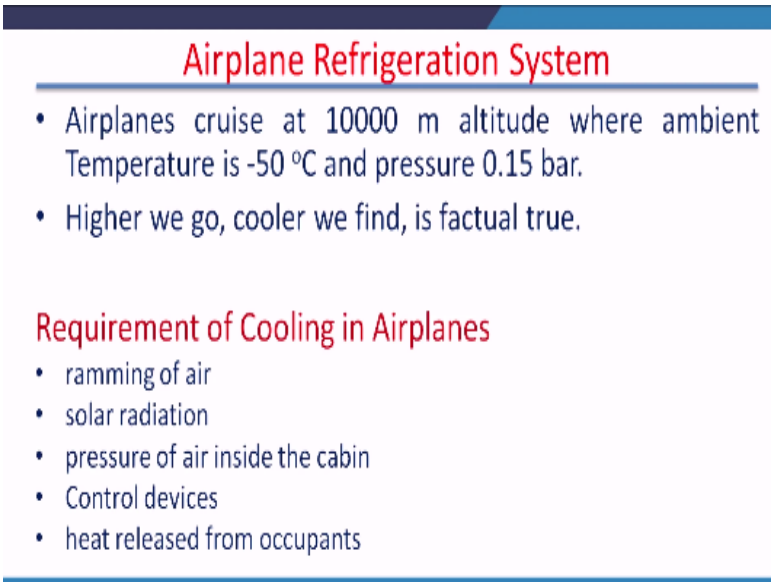

It airplane in some of the part of the world it is called aeroplane and airplane.

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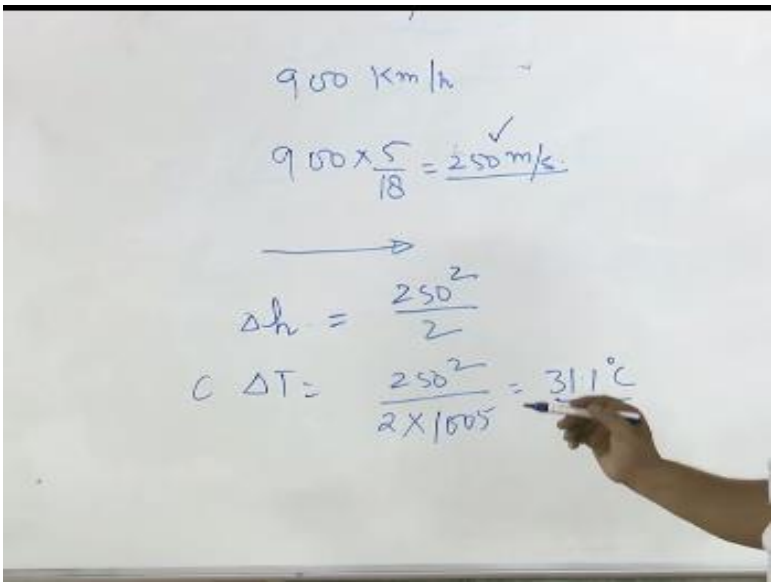

Both are same aeroplane and airplane both are same this terminology airplane is mostly used in US and Canada and rest of the world in most of the part of the world it is called aeroplane, so whether it is airplane or aeroplane the question is whether cooling is required in aeroplane because the temperature is -50 degree centigrade where the in the area where it is moving so the cooling is really required for aeroplane.

Cooling is definitely required for aeroplane there are certain reasons the reason being the learning of air when the plane is moving with the velocity of 1000 kilometers per hour let us say our plane is moving for the sake of convenience ninety 900 kilometers per hour if we convert this velocity into meter per second if we convert this velocity into meter per second it is going to be 250 meters per second.

The air is coming on the plane grouse plane is moving into the air or vice versa the air is coming we can assume that air is coming over the plane with the velocity 2 meter per second and this kinetic energy is imparted to the plane surface in that case using law for open system H is equal to how much $250^2/2$ $V^2/2$ and this is ΔH and this is equal to ΔT is going to be $250^2/2$ multiplied by CP. This is CP ΔT so x CP is 1005 because CP for air is 1005 joules per kg Kelvin so this is

going to be equal to 31.1 degree centigrade this is the temperature rises is the order of temperature rise when high velocity air strikes the plane and kinetic energy of air is converted into the enthalpy of air in addition to that there are solar radiations beyond the.

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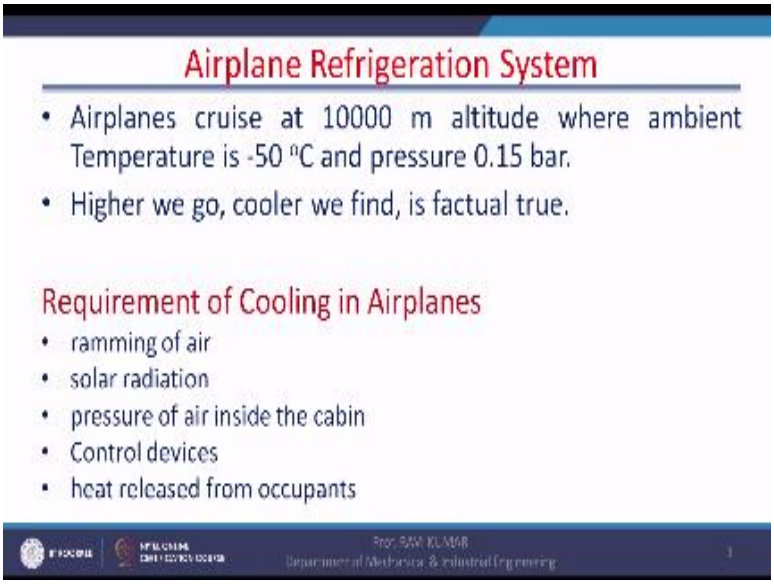

Earth atmosphere.

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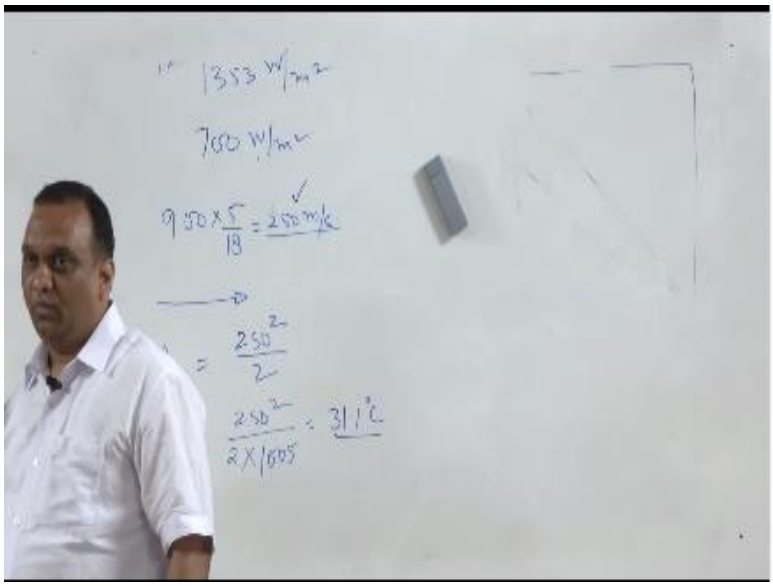

It is an estimate the solar radiations are 13 53w/m^2 even on the earth for example even in it at this place the solar radiations are approximately of the order of 700w/m^2 and the area where the plane is cruising we can always assume that the radiations falling on the plane surface is approximately 1000w/m^2 or 1kw/m^2 this much heat is coming to the plane pressure of air inside the cabin is also an issue because outside pressure is.

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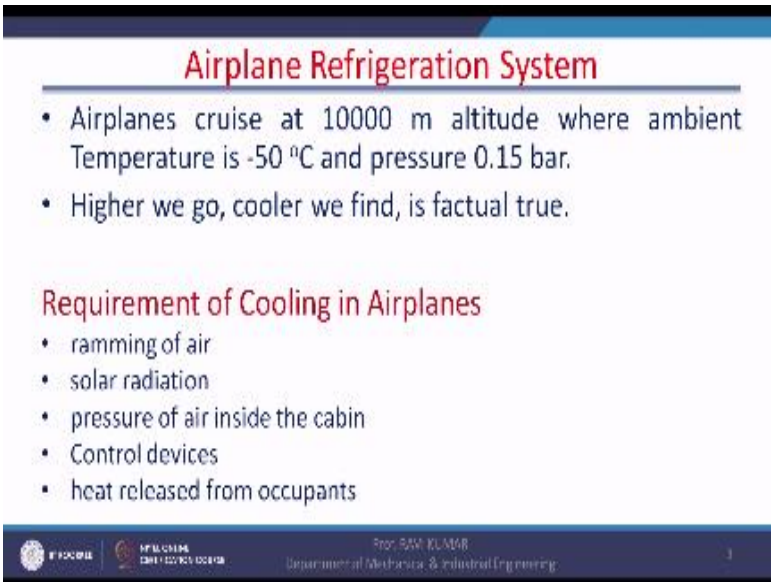

0.15 bar so air has to be pressurized before it is supplied to the kevin a lot of heat is dissipated by the control devices also there is a lot of electronics in the plane and these electronic devices they also dissipate the heat and if we take a rough estimate let us say if a plane of a passenger capacity of 150 approximately 6 to 7 tons of cooling will be required for cooling the electronic devices itself heat leads from the occupants of the plane when they are sitting and are not involved in any activity they add night they dissipate 90w of heat as sensible heat and 30w of heat as latent heat total is 120w or roughly.

We assume 100w per passenger so if there are 200 passengers in the plane so 200 multiplied by 0.1kw it is 20kw and 10 to 20kw if you divide by 3.520kw divided by 3.5 if it will be approximately how much 25.7 tons of refrigeration will be required so there are many sources for heat transfer to the plane and because the plane engine is also at a very high temperature so through conduction or radiation the heat is also transmitted from the engine of the plane so finally cooling in a plane is required now the second question is why use air cycle.

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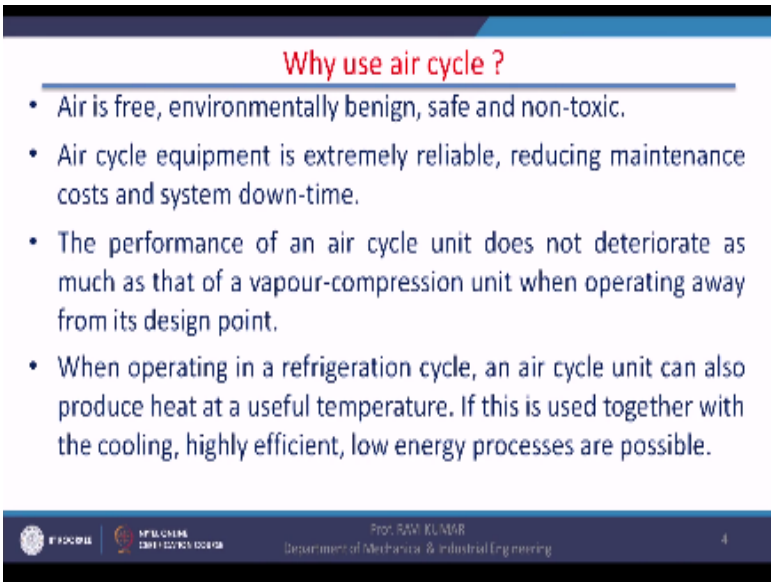

We can have many other cycles also but why we want to use air as a refrigerant for cooling in aero plane first of all air is cheap that is always a consideration when we purchase anything that it the cost has to be low environmentally Bennigan's safe and non-toxic that is the I mean property of the air which has to be highlighted because any gas we use in aero planes has to be non-oxide, nontoxic inflammable safe and environment friendly.

Air cycle equipment are extremely reliable, because the pressure ratio in air cycle is less in comparison to the pressure ratio in vapour compression cycle. So the maintenance cost is less and systems are reliable, so reliability is also another issue in airplanes the system whatever the system we use in airplane has to be reliable. The performance of air cycle you need does not deteriorate as much as that of vapour compression unit when operating away from it design point.

So off design performance of air cycle is very good, because any instrument even if you purchase automobile for yourself you never drive your car or a scooter on design conditions like for example if you have a motorcycle, motorcycle optimal device design condition ideal road conditions speed 45 km/h but you never drive motorcycle always at 45km/h when you are in

congested area you are driving in first gear maybe 3 km/h, right. So off design performance of such machines carry a lot of importance.

So for air refrigeration cycle it is off design performance is also good when operating in a refrigeration cycle this air refrigeration cycle also produces heat because heat is rejected and this rejected heat can be used for other processes in the plane which require low level of energy.

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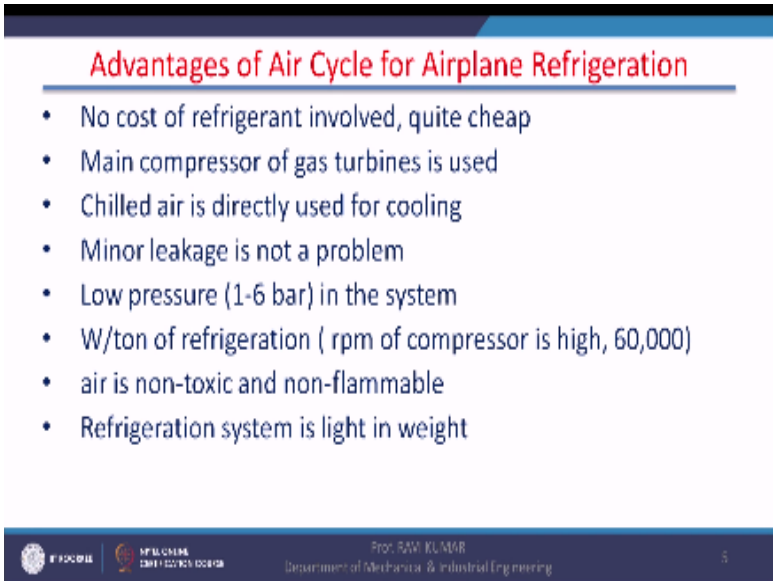

Advantages of air cycle for airplane refrigeration no cost refrigeration involved the air is quite cheap main compressor of gas turbine is used so in a plane because the plane is powered with the help of a gas turbine and for the gas turbines a compressor is used. So the same compressor can also be used for compressing the air for the purpose of compression so a separate compressor is not required if you use air compression cycle if you use any other cycle vapour compression cycle it dedicated compressor shall be required for refrigeration cycle.

But if you are using air standard cycle or sorry this air refrigeration cycle in their cycle the same compressor which is used for the gas turbine of engine can be used for air refrigerant purpose also. Chilled air is directly used for cooling so chilled air you can directly inject into the cabin

this is not possible in the other vapor compression cycle where some chemicals are used as a refrigerant because in this cycle the benefit is that the air is used as a refrigerant so air chilled air can directly be injected to the cave in minor leakage is not a problem because if there is a leakage up in the atmosphere 10 kilometers away from the Earth surface if there is a minor leakage that can be resolved this issue can be resolved by a tapping air from the outside.

But in if you are not using air instead of air if you are using some other because as a refrigerant this may not be possible low pressure in the system this low pressure leads to low maintenance I have discussed earlier weight per ton of refrigeration is low in air refrigerant cycle it is very light in weight so that is for any aircraft application this is one of the major criteria the system has to be very light in weight so weight Petron of refrigeration in air cycle is low and because the RP of the compressor is very high it can go up to 60,000 rpm.

Air is non-toxic and non-flammable we have already discussed it and refrigeration system is light in weight just now we have discussed now there are certain disadvantages because they are certain advantages of air cycle refrigeration cycle they are certain disadvantages also.

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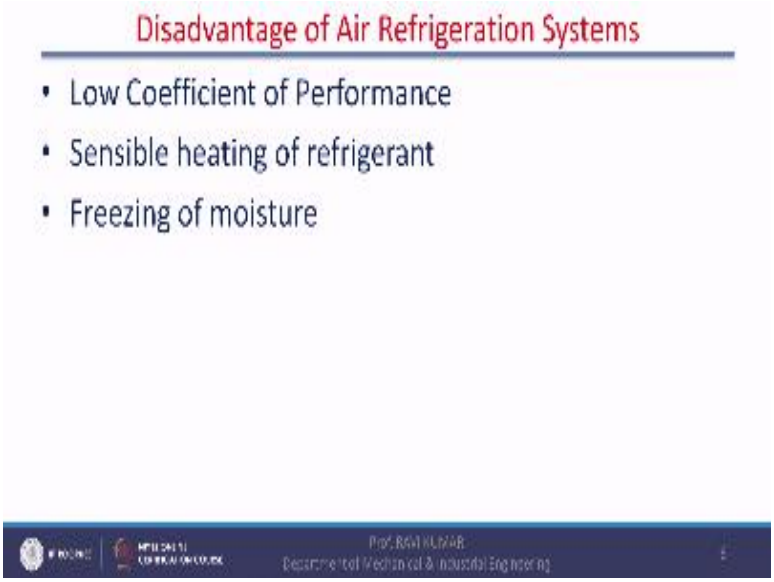

Low coefficient of course there is a major disadvantage of air referential cycle which always goes against it and that is why we do not use air recreation cycles in our buildings in our buildings we do not use air refrigerant cycles the reason being the COP of the Ray of the air reaction cycle is approximately 0.4.

COP of it is closed 0.4 approximately 0.4 COP of vapor compression cycle is approximately nowadays it is it goes up to 3.5, so it is 8 to 9 times of this so if we use air cycles this can be also be mooted that why do not is it is so beneficial air standard cycle why cannot we use the air standard cycle air refrigerant cycles for our buildings. We cannot use it is not advisable to use air refraction cycles for the building because the COP coefficient of performance of air refreshing cycle is very, very low in comparison to the coefficient of performance of vapor compression cycles. Second thing is sensible heating of refrigerant takes place if you look at the air refrigeration cycle.

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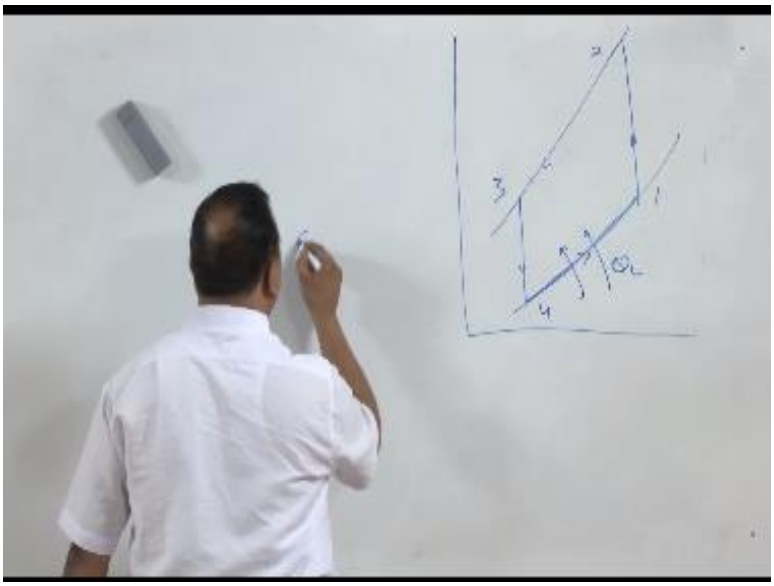

The cooling effect we get from here because process four-to-one the air extracts heat from the surroundings and that produces the cooling effect now in order to produce this cooling effect the sensible heating of air takes place CP δT. CP ΔT, now in vapour compression cycle vapour

compression refrigeration cycles,, the heat this heat transfer during refrigeration and heat rejection takes place, during boiling and condensation.

We will discuss vapour compression cycles later on, in details but here I must tell you in vapour compression cycle this process of heat extraction from the surroundings, during this process the boiling of vapour takes place, in vapour compression cycle similarly during heat release during condensation it is not sensible cooling in vapour compression cycle. it is condensation of the vapour.

It has certain advantages because here we are making use of latent heat of the fluids, so small quantity of the fluid has to be circulated in the system, in order to produce the same kind of refrigerating effect. now because here the sensible heating is taking place mass flow of air has to be very high in comparison to the mass flow of refrigerant in compression of in case of vapour compression system, and if obviously there is another problem of freezing of moisture in the air, if some moisture in the air is present, it will get freeze and it will cause problems in operation of the system types of airplane refrigeration system.

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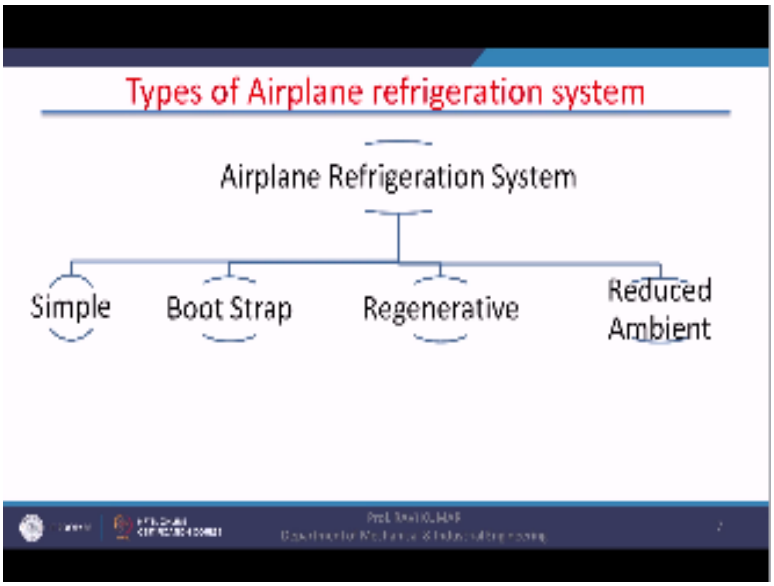

So there are four types of airplane refrigeration systems simple, bootstrap, regenerative and reduced ambient. Simple is not that simple I mean like this simple air refrigeration cycle, it is a modification of this cycle right now we will discuss that, now another type of system is a bootstrap system, bootstrap system the output of this expander is used for further compression of the air.

So that we can get the maximum refrigerating effect, so these two are there then these two type of system simple and bootstrap can also have arrangement for evaporative cooling, so you have ready cooling will further enhance the performance of the system, a third one is a regenerative system and fourth one is reduced ambient system.

so we will discuss these systems one by one, let us take simple air a refrigeration system, the simple are if racial system as you can see in the figure, it is a at point zero, at point zero we assume that air is coming with a certain velocity and a pic I will draw this process.

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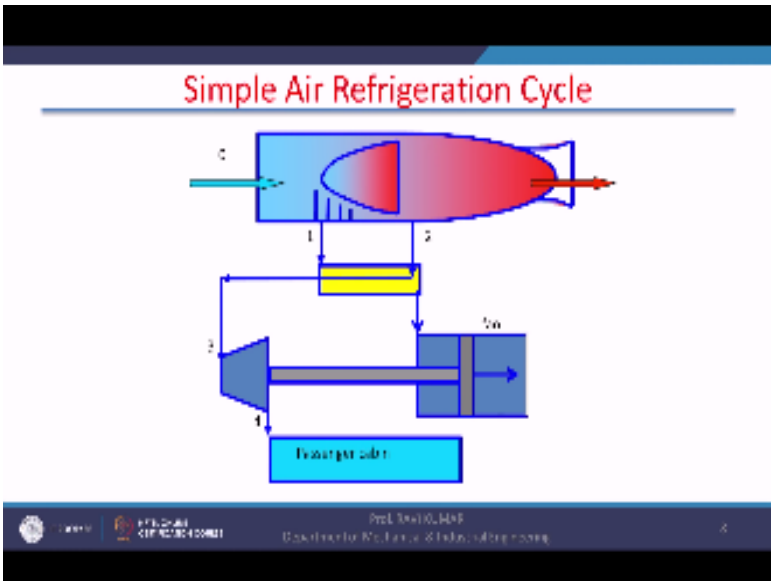

On temperature entropy diagram, stagnation of air takes place due to this stagnation the pressure of the air arises and we get state one, this is this action is known as ramming action, so the

kinetic energy of air is converted into the pressure energy, and in this process the pressure of air also Rises, this state one is also shown in the figure.

now we are using here the same compressor as it is used for the gas turbine of the aircraft, now out of this compressor, at state 1 the stagnated air is attained this stagnated air is compressed, in the compressor and we get state 2, as shown in the figure.

now this at state 2, the air is at very high temperature, and high pressure as well. now this air is cooled with the air available at state 1, and cooling of air takes place and that is process 2 to 3, now at 3 there is an expander, now at3, there is an expander and this expander is used for expansion of air. the expansion of air takes place and it is not expanded up to zero, it is expanded up to here, above because this pressure is 0.15 approximately bar.

so air is expanded up to 1 bar, or 0.9 bar, then it is supplied to the table the power developed in the expander, power developed in the expander is used to run the fan this air is also used for cooling purpose, now second cycle is bootstrap air refrigeration cycle, bootstrap mean you must have seen a strap on the boot so, boot is means over and above. So here in bootstrap cycle initial processes remain same I mean.

If you take process 0 to 1 ramming action takes place now 1 to 2 compression takes place in a compressor and after the compression the cooling is done, after the compression the cooling is done up to state 3 in a heat exchanger and this cooling is again done with a air available at state 1 after state 3 another compressor is provided, this compressor is powered by the turbine which is also an expander.

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So this 3 state 3 air is further compressed air is further compressed with another compressor and we get the state 4, after state 4 again the cooling takes place and we get the state 5 the cooling is again done with the air available at the entry of the compressor, so we get list five state five and after state five expansion takes place in expander and air is supplied to the cable. Now here in this case how it is beneficial because here in this case expansion is taking place at higher pressure this is 2 P 4 so P 4, P 4 is greater than P 2 or the pressure ratio instead of this if we had expanded the air from here we could have got higher temperature.

Since we have compressed it and cooled it and we have attained the state 5 you can see we are getting a lower temperature. So the benefit of the bootstrap type of refrigeration system is that the output of the turbine, because this bootstrap type of system is used for aircraft with relatively higher speed bootstrap air refrigeration cycle is used for the aircraft where speed is relatively high then in the case of simple a refrigeration cycle.

So in a bootstrap cycle air fan for the purpose of cooling is not required so the fan can be eliminated and this fan instead of this power of expander going to the fan, it goes to the compressor so, compressor is driven by the expander or the turbine and this compressor gives the

additional pressure rise in the air, which results in lower temperature after expansion at state 6. Now I complete my lecture here in the subsequent lectures, I will take remaining two types of refrigerant system that is a regenerative type and reduce ambient type.

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